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Resilience Bonds: un nuovo approccio al rischio catastrofale per il settore assicurativo.

Marcello Galeotti
University of Florence, marcello.galeotti@unifi.it
Giovanni Rabitti
Heriot-Watt University, Edinburgh, G.Rabitti@hw.ac.uk
Emanuele Vannucci
University of Pisa, emanuele.vannucci@unipi.it

Agenda

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- Cat Risk in Italy: the insurance gap

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Cat Risk local and global scale

Climate Change entails economic risks

- **in the short term and also on a local scale** (e.g. hydrogeological risk), damages to be compensated (insurance, public administration) and infrastructures to be restored (roads, production units, residential units, ...)

- **in the long term and on a global scale** which imply the need to finance the transition to sustainable production systems.

Cat Risk worldwide

Flood in Deutschland in 2021.

Cat Risk worldwide

According to the 2022 Sigma, Swiss Re Institute report "Natural catastrophes in 2021: the flood gates are open"

Natural disasters in 2021 resulted in a total global economic loss of 270 billion $\$$ and insured losses of 111 billion $\$$.

The long-term trend of insured losses increasing by an average of $5-7\%$ per year worldwide continues.

Cat Risk worldwide insurance gap

The report warns that although insured flood losses are at a record level, the related global protection gap remains large.

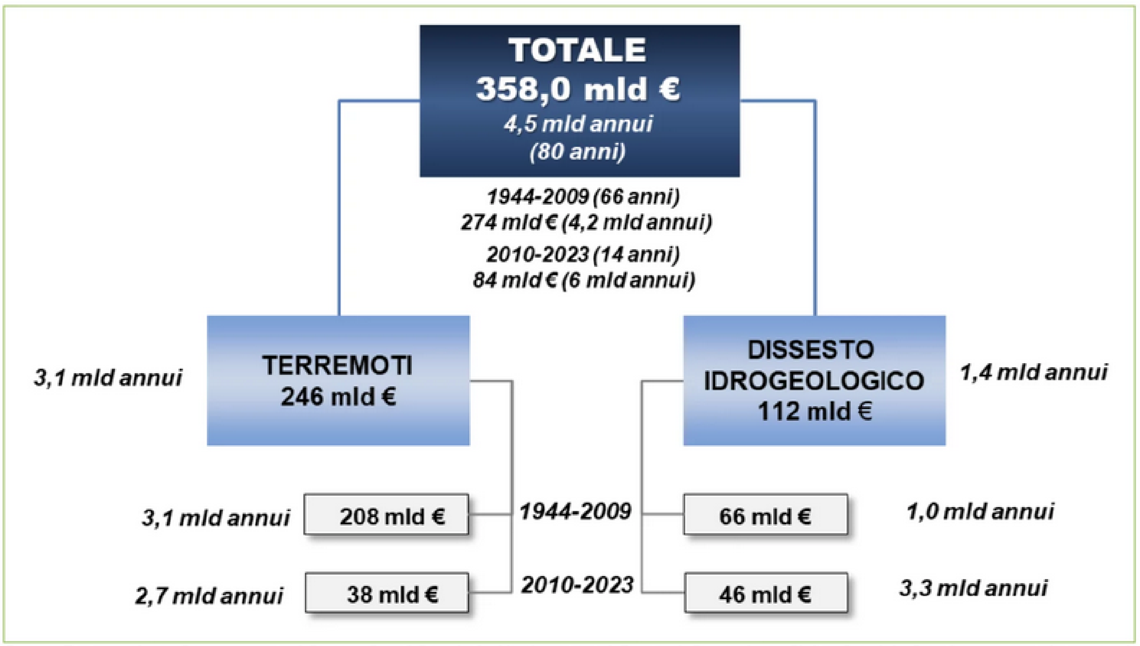
Large-scale floods were among the main events driving global insured losses from natural disasters and over the past decade, **only 5% of severe flood losses were insured in emerging markets and 34% in advanced economies**, indicating a large global insurance protection gap.

Cat Risk in Italy

Hydrogeological damages in Tuscany in 2025

Cat Risk in Italy

"Lo stato di rischio del territorio italiano nel 2023", Report from Cresme (Centro di ricerche di mercato) for Ance (Associazione nazionale costruttori edili).



Fonte: Elaborazione Cresme su dati Centro Studi Consiglio Nazionale dei Geologi, Protezione Civile, Servizio Studi camera dei deputati, MASE, ISPRA, Agenzia per la Coesione Territoriale, Corte dei conti

Cat Risk in Italy

ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientaleh) and JRC (Joint Research Center of the European Commission) researches in 2020 both agreeing on an annual figure of around 3 billion euros in damages for private property and other 3 billion euros for public goods.

Antonio Coviello, Cnr-Iriss:
Scientific studies have predicted that climate change will cut the Italian GDP per capita of the 0.89% in 2030, 2.56% in 2050 and 7.01% in 2100.

Cat Risk in Italy: the cost of mitigation

Arno's overflow channel in Pontedera.

Cat Risk in Italy: the cost of mitigation

Centro Studi del Consiglio Nazionale degli Ingegneri (CNI): **around 26 billion euros for a "full" securitization of riskiest areas in Italy** and around 4.8 years the average time for the completion of a mitigative infrastructure.

Ispra (Istituto superiore per la protezione e la ricerca ambientale) estimates around 7 billion euros the Environment Minister allocated amount for facing hydrogeological risk in the last 20 years.

Cat Risk in Italy: insurance gap

In Italy, the total economic losses since 2011 (up to 2023) caused by natural disasters were 58.1 billion \$ (around 6 billion a year), insured losses were 6.3 billion and **the insurance protection gap was 51.8 billion \$ (89%)**.

In Italy citizens believe that the State is a guarantor of last resort willing to take charge of the reconstruction: insurance coverage for catastrophe events is scarcely widespread, 88.7% of policies do not have any extension (source ANIA), **residential units insured against the risk of natural disasters is 4.9% of the 31.2 million registered by ISTAT.**

Cat Risk in Italy: insurance gap

For this insurance protection gap, **the 2023 financial law* for 2023 made insurance coverage mandatory for production units** (for large companies in force from yesterday, 1 April 2025, while for small and medium-sized companies there is a postponement of a few months).

One of the objectives that has long been in the sights of the Italian political decision-maker is to find some form of incentive, with mandatory or semi-mandatory formulas as in other European countries, also for residential units. In France a form of semi-compulsory tax benefit has led to CAT-NAT coverage for residential units in the order of 85-90%.

*https://www.senato.it/leg/19/BGT/Schede/Ddliter/57654.htm

A new role for the insurance sector: financing resilience

Lloyd's CEO, John Neal said in 2021: **"Insurers can not absorb huge losses after natural disasters especially with this trend of climate change**, but the insurance industry's got 35 trillion under management, so we're part of the solution, if you like, of putting our assets at play to support transition".

He even affirmed that there is **the need of a partnership between governmental authorities and insurance companies to incentive investments by private companies for green transition.**

A new role for the insurance sector: financing resilience

Jérôme Jean Haegeli, Group Chief Economis at Swiss Re, confirms:

Growing losses due to floods are becoming increasingly evident. **There is a growing urgency for action to increase the resilience of societies around the world.** Together with the public sector, insurers are well equipped to drive urbanization away from high-risk areas and invest in protective measures such as green infrastructure. This keeps assets insurable while improving growth prospects.

A new role for the insurance sector: financing resilience

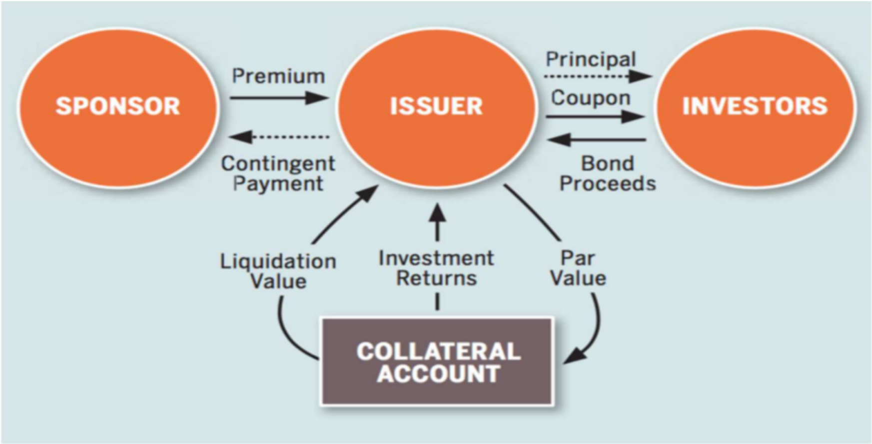
EIOPA. The role of insurers in tackling climate change: challenges and opportunities. 2023.

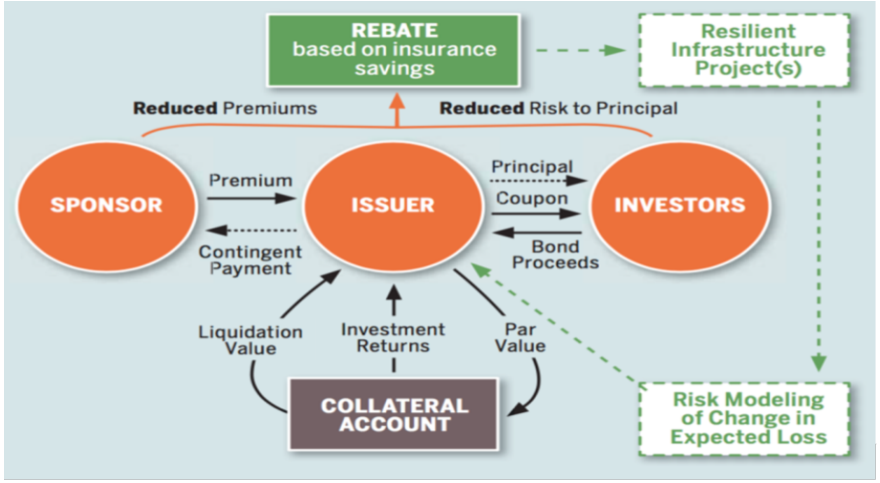
"Insurers can develop innovative insurance products that incentivize climate related risk prevention, for instance through offering lower premiums to policyholders implementing climate related adaptation measures."

Our proposal: from Cat to Resilience Bonds

"Innovative insurance products ... offering lower premiums": the Resilience Bonds can be the realization of this proposal.
In fact Resilience Bonds are Cat Bonds with the addition of a financing scheme, by the application of premium discount, for the implementation of climate related adaptation or mitigation measures which can be applied both in a local short-term scenario or in encouraging the green transition in a global long-term scenario.

Cat and Resilience Bonds financial schemes





An elementary example of Resilience Bonds financial scheme

Economic entities involved in the Resilience Bonds financial scheme
- **the entities (firms and P.A.) exposed to Cat risk** (the insured if they decide to buy insurance coverage)
- **the insurance system** (issuers of Resilience Bonds)
- **the public administration** (insured and insurer/reinsurer)
- **the investors** (in Resilience Bonds)

The public administration (P.A.) can be considered both the insured for damages to public goods and the insurer/reinsurer for the integration in the payment of damages to private property, filling (or trying to) the insurance gap.

An elementary example of Resilience Bonds financial scheme

Let assume an average annual damage (e.g. 10 monetary units) with fluctuations that can put the P.A. in difficulty (the use of general taxation may not be sufficient) when they give rise to very high levels of catastrophe damage not covered by insurance system.

Note that even in case on insurance coverage, part of the damage will remain in charge of the P.A.

An elementary example of Resilience Bonds financial scheme

What strategies can entities (firms and P.A.) exposed to catastrophe risk implement?

I) To adopt a passive strategy, paying for damages as they arrive

II) To adopt a classic insurance scheme

III) To adopt a resilient (economic-operational) strategy

Case I): passive strategy (no-insurance)

- The firms and the P.A. pay on average 10 each year, with the difficulties already mentioned in the years with the highest level of damage
- The insurance system is not involved
- The financial market is not involved

Total profit/loss in n years
- Insured has expected loss $-10n$ (maintaining the risk of covering large losses)
- Insurance system 0
- Investors 0

Case II) Classic insurance scheme (in case companies accept to cover the risk)

- The firms and the P.A. pay a pure premium 10 (equal to expected loss) plus a loading 1, total 11
- The insurance system receives the gross premium
- The financial market is not involved

Total profit/loss in n years
- Insured pays $-11n$ (avoiding large losses)
- Insurance system has expected profit n (accepting the risk of covering large losses)
- Investors 0

Case III) Adoption of a resilient strategy

Assume that a **mitigating measure (infrastructure) has a cost of 42 and it allows to reduce risk exposure by 7 each year and that the completion time is 4 years** (therefore for the years following the completion time the expected loss is 10-7=3).

It is necessary to underline the **crucial role of an engineering expertise on hydrogeological risk that certifies costs, timing of implementation and risk reduction capacity of the mitigation measure.**

Case III) Adoption of a resilient strategy

Assuming the point of view of the insured (firms and P.A.), the **break-even point, i.e. the time horizon after which the resilient scheme becomes convenient compared to another strategy** (passive or classic insurance), can be evaluated.

It is interesting to analyze the case of no-catastrophe, since in the opposite case to have an insurance coverage (both with the classic insurance and with the resilient strategies) is advantageous compared to the no-insurance approach.

Case III) Adoption of a resilient strategy

The break even point compared to the classic insurance strategy is given by the number of years T that solves the equation (a zero interest rate is assumed), which is the solution of the following equation

$$(10+1)T = 42+(10+1)4+(3+1)(T\text{-}4)$$

and hence T=10.

Note that compared to the approach of non-insurance, the break even point would be 11.6 years.

Case III) Adoption of a resilient strategy

In these first 10 years

- the insured pays 110 (68 for insurance and 42 for the mitigating measure)

- the insurance system receives 68 and it can fix a constant premium of 6.8 to be applied over 10 years instead of receiving 11 for the first 4 years and 4 for the next 6 years: this can be considered a first cooperative action for implementing mitigation measures by the insurance system.

Case III) Adoption of a resilient strategy

The insurance system issues a Resilience Bond and let assume that the adequate risk premium is given by a coupon=0.5 (the same risk premium investors would ask in case of standard bond for a credit risk of the same level) with maturity 10 years.

Total profit/loss in 10 years
- Insured pays $-42 - 11 \cdot 4 - 3 \cdot (10 - 4) = -110$
- Insurance system has expected profit $0.5 \cdot 10 = 5$ (transferring part of the risk of large losses to financial markets)
- Investors has expected profit $0.5 \cdot 5 = 5$ (accepting the risk of loss in case of catastrophe as they accept the credit risk in the "standard" financial market)

Case III) Adoption of a resilient strategy: the win-win-win strategy (?)

First win.
The exposure to Cat Risk is "costly" in terms of Solvency Capital Requirement, so **transferring part of this risk to financial markets, the insurance system can adopt a premium discount, so giving full effect to the Resilience Bonds financial scheme**, renouncing to a part of its expected profit.
This kind of decision may derive from the statements of insurance industry representatives who are behind this resilient approach.
P.A. can co-finance the application of this discount, since as the payer of last resort it has an advantage in reducing the overall risk.

Case III) Adoption of a resilient strategy: the win-win-win strategy (?)

Second win.
With Resilience bonds, as with green investments, investors may be **willing to give up part of their expected earnings (greenium effect), to feel an active and positive part in the journey towards sustainability.**

Third win.
Using these transfers of earnings from the insurance system and financial markets, **for firms and P.A. the break even point can even be shortened.**

Some papers of our research group

- Castelli F., Galeotti M., Rabitti G. (2019). Financial Instruments for Mitigation of Flood Risks: The Case of Florence. Risk Analysis, 39(2):462–472.

- Pagano A.J., Romagnoli F., Vannucci E., (2021). Climate change management: a resilience strategy for flood risk using Blockchain tools. Decisions in Economic and Finance, pp. 1-14; ISBN:1593-8883.

- Galeotti M., Vannucci E., (2023).
Green economy with efficient public incentives. Decisions in Economic and Finance, (46) pp. 667-680.

- Feofilovs M., Pagano A.J., Romagnoli F., Spiotta M., Vannucci E. (2023). Climate change-related disaster risk mitigation through innovative insurance mechanism: a System Dynamics model application for a case study in Latvia. Risks, 12(3):43, 2024.

The model presented hereafter is in
- Galeotti M., Rabitti G., Vannucci E. (2025), A quantitative model for green transition resilience bonds, submitted to European Actuarial Journal (2025).

A dynamic model to describe the potential of Resilience Bonds

In our model there is a set of firms (policy-holders) exposed to Cat Risk, which could be mitigated through the implementation of green technologies.

Insurance companies and P.A. cooperate in financing the green transition and thus for Cat Risk reduction:
in case some firms decide to switch towards a green transition, then companies discount the insurance premiums and the public administration can contribute for example by applying tax benefits and/or acting as a reinsurer for the risk above a certain level (so reducing the cost for capital requirement for the companies).

Model's dynamics

A reasonable assumption: if the share of green firms increases, then Cat Risk and consequently also the interest rate requested by investors in Cat bonds both decrease.

This way a dynamical interaction takes place, involving the bonds interest rate and the share of green firms.

Model's dynamics

We illustrate two main scenarios of the system:

- in one all the trajectories converge to an optimal equilibrium, where all the firms adopt green technologies and the rate (or spread) of the Resilience bonds is minimum

- in the other scenario, instead, a "poverty trap" appears, meaning that the trajectories starting in that region (poverty trap) converge to a sub-optimal equilibrium, where the share of green firms is lower than 1 and the Resilience bonds interest rate is not minimum.

Model's dynamics

The discrete time dynamics takes place in a rectangle R, where $x \in [0,1]$ is the share of green firms $r \in [r_0, r^*]$ is the Resilience bond interest rate (or spread).

$$\begin{cases} x(t+1) = \exp\left[(x(t)-1)\, f\left(x(t), r(t)\right)\right] \\ r(t+1) = r(t) g\left(x(t), r(t)\right) \end{cases} \tag{1}$$

We need some "natural" assumptions for f and g (see the paper for details) which are both positive function.

A coherent proposal

We propose possible shapes of the functions f and g.

$$f(x,r) = \lambda P_v$$
$$g(x,r) = \left(xp_1 + (1-x)\,p_2\right)\left(\frac{r^*-r}{r^*-r_0}\frac{1}{p_1} + \frac{r-r_0}{r^*-r_0}\frac{1}{p_2}\right)$$

with P_v the insurance premium paid by green firms on which it depends $f(x,r)$, the impulse for the proportion of green firms x.

The impulse for the interest rate, $g(x,r)$, depends on the current "average risk", given by the current "mixture" of green and no-green firms.

A coherent proposal

Insurance premiums for no-green and green firms (we can consider the typical charge of insurance premiums, so it could be higher than the expected loss)

$h, k, \lambda > 0$ are expressed in monetary amounts

p_1 the probability that a green firm contributes to the catastrophe

p_2 ($> p_1$) the probability that a no-green firm contributes to the catastrophe

hp_2 is the insurance premium paid by no-green firms

A coherent proposal

We assume that P_v the premium paid by green firms, is expressed by

$$\lambda P_v = hp_1 - k\left(r^* - r\right)$$

with $p_1 = a - bx$ being the probability that a green firm contributes to the catastrophe.

Specifically a $(< p_2)$ is the probability that a single green firm contributes to the catastrophe (technological improvement effect) while a "sinergy" effect is given by the level x multiplied by a "sinergy" intensity b $(< a)$.

Premium discount

The discount $k\,(r^* - r)$ applied to the green firms premium is assumed to be a function of the current interest rate level r and of the upper bound r^*: the lower is the current rate, the higher is the discount.

The intensity of discount k is a parameter controlled by the insurance system.

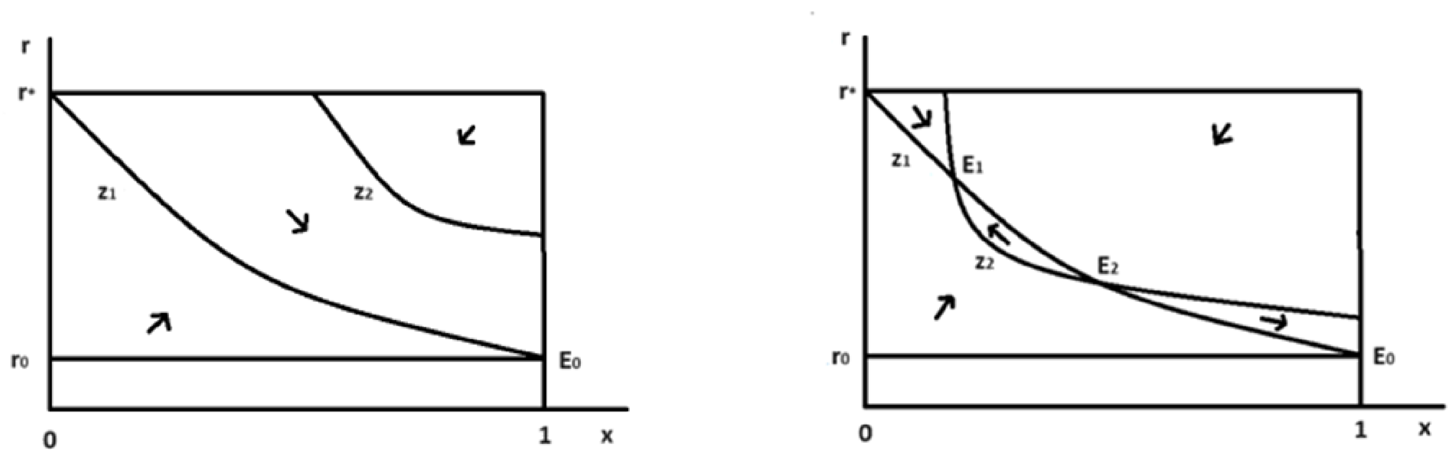
Local analysis

The curve Z_1) $g(x,r) = 1$ (the interest rate is stable)

The curve Z_2) $[(x-1) f(x,r)] - \ln x = 0$ (the proportion of green firms is stable)

The number of intersections of these two curves is generically even. We consider the cases when it is zero or two.

Local analysis



Actually the dynamics is discrete, but the arrows give an idea of dynamical directions in the various regions bounded by the two curves.

Global analysis

In order to proceed to a full investigation of the global dynamics we introduce a further assumption.

We assume $p_2 \leq \frac{2r^* - r_0}{r^*} a$ and $b < \frac{r^* - r_0}{2r^* + r_0} a$

Such assumptions pose bounds to the benefits of green technology and its diffusion. Grossly speaking:
- the risk caused by no-green technology is no more than the double of that caused by green technology
- the risk reduction due to the diffusion of green firms can at most halve the risk caused by the green technology.

Equilibria of the model

Taking into account the previous assumptions, we are able to illustrate the dynamics in the two main scenarios of the system.

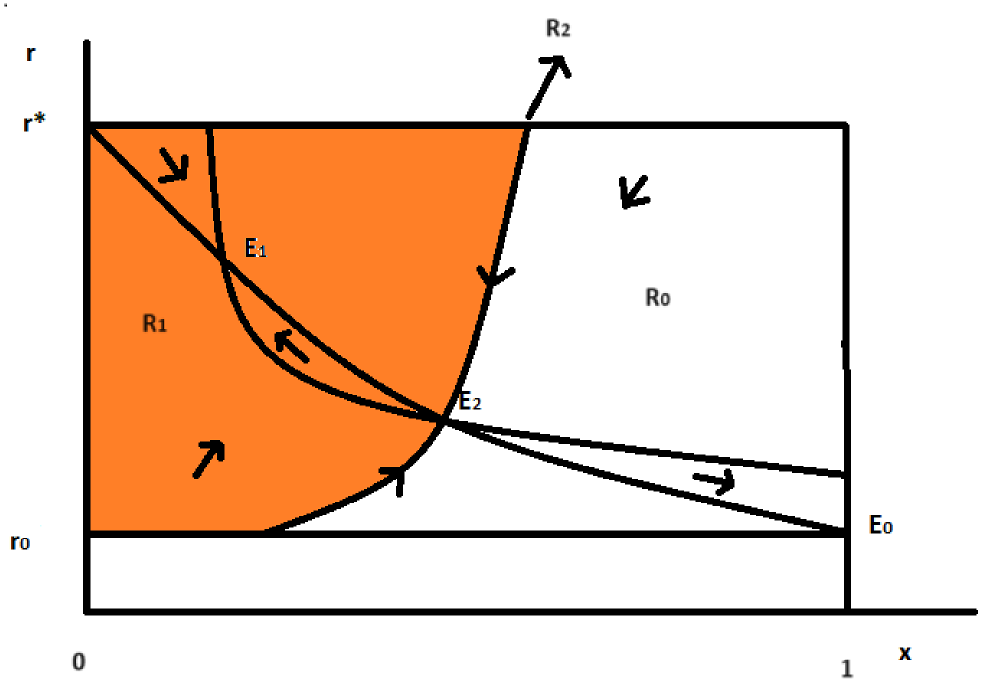
- In case the two curves have no intersection, we have the only equilibrium E_0. Then E_0 is a global attractor in R.

- In case the two curves have intersections, we assume the equilibria are three: E_0, E_1 and E_2.

Then R contains two regions, R_0 and R_1. In R_0 all the trajectories converge to E_0, whereas in R_1 all the trajectories converge to E_1. R_0 and R_1 are separated by an invariant curve R_2 containing E_2.
Thus, $R = R_0 \bigcup R_1 \bigcup R_2$.

The poverty trap

We can refer to R_1 as a "poverty trap", since trajectories lying in R_1 tend to a sub-optimal equilibrium.



Implementation for flood risk prevention in Italy

A comprehensive analysis of flood catastrophic risk in Italy is presented in three reports
- IVASS (by Riccardo Cesari and Leandro D'Aurizio, 2020)
- Bank of Italy (by Michele Loberto and Matteo Spuri, 2023)
- Ministero dell'Economia e delle Finanze (BTP Green Allocation and Impact Report, 2023).

The IVASS report indicates that in the highest-risk category, in our model corresponding to the probability p_2, and the lowest risk category, in our model associated with the probability level $p_1 = a - b$ when $x = 1$, the ratio is approximately double.

Cat bonds market analysis

Sakai Ando et al. (Sovereign Climate Debt Instruments: An Overview of the Green and Catastrophe Bond Markets, 2022) highlight that Cat bonds yields and the coupon rate are positively correlated, with a time lag, compared to estimates of catastrophic risk updated based on loss experience as it occurs.

Regarding our model, we can derive from their analysis the range to associate with parameters r_0 and r^*, spanning from approximately 4% to about 9%. Since these levels of Cat bonds spreads are valid in a regime where there is not full adherence to risk mitigation, one can also imagine a minimum spread level lower than the observed 4%.

Sensitivity analysis

Consider the following reference parameterization, which can represent a rescaled model of the Italian scenario

p_2	0.1
a	$0.65p_2$
b	$0.3p_2$
r^*	0.09
r_0	0.02
h	35
k	$\frac{h}{3}$

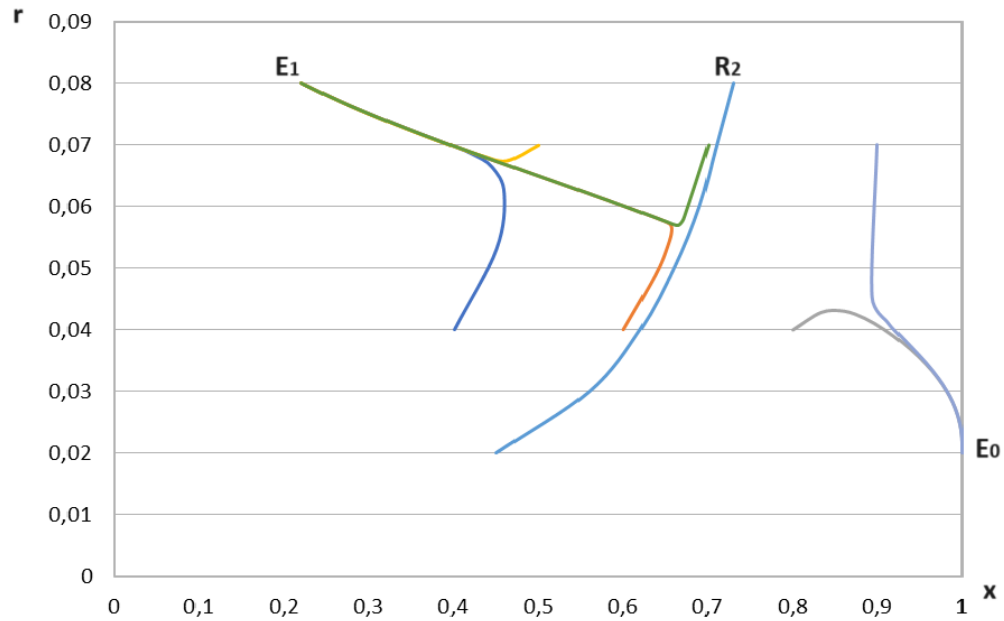
Sensitivity analysis

All figures display the simulated trajectories starting from the same set of six initial points $x(0)$ and $r(0)$ having coordinates:

- $x(0) = 0.5, 0.7, 0.9$ and $r(0) = 0.07$
- $x(0) = 0.4, 0.6, 0.8$ and $r(0) = 0.04$.

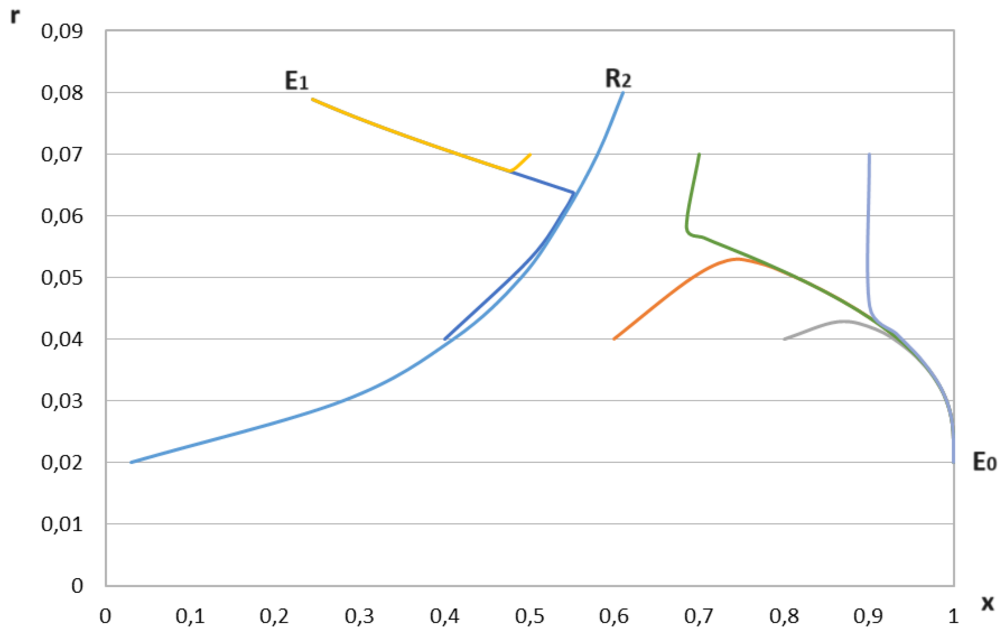
Moreover, the graphical representation of the curve R_2 is provided, observing how trajectories starting from these initial points will converge partly towards the virtuous equilibrium E_0 and partly towards the poverty trap E_1.

Simulation with the reference parametrization



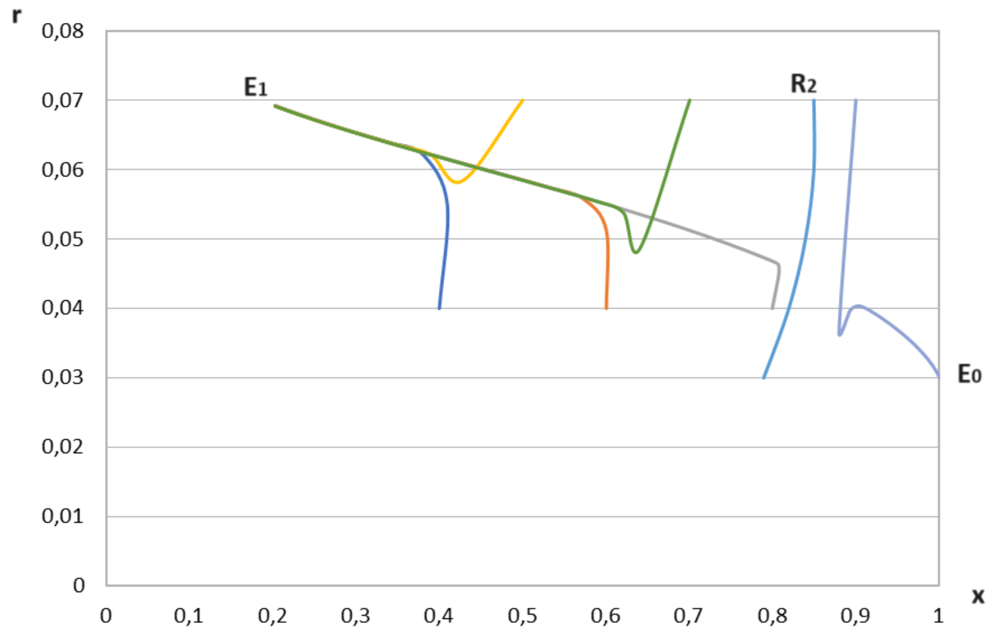
Starting from an initially too low concentration of companies that have already implemented flood risk mitigation measures will not lead to full program adoption.

Simulation with an higher insurance premium discount, $k = 0.4h$



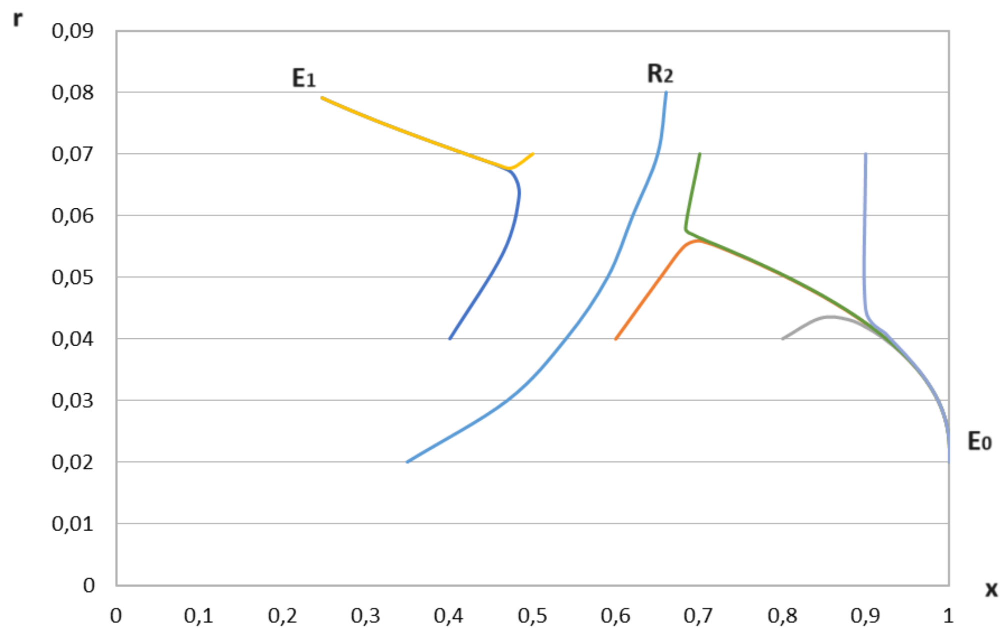
As the discount increases, more firms tend to join the project, eventually reaching full participation.

Simulation with a smaller range for the Cat bonds spread, $r^* = 0.075$ and $r_0 = 0.03$



The tolerable risk level in the Cat bonds market, both in terms of the offerings by the issuer and the acceptance by investors is crucial for reaching full participation.

Simulation with higher effectiveness of risk mitigation strategies, $a = 0.66$ and $b = 0.31$



A higher effectiveness of risk mitigation strategies facilitates the achievement of the virtuous equilibrium E_0.

Policy implications

We have emphasized that the proposed model describes how the use of a resilient framework in flood risk mitigation (in this case, applied to a scenario based on data from Italy but adaptable to different contexts) may or may not succeed.

Its success depends on whether it encourages or discourages adherence to the risk mitigation strategy by units exposed to risk, depending on the scenario in which it is applied.

Policy implications

To determine that, it is necessary to define:

- the possible choices made by policymakers, including the level of cooperation between insurance companies and the public system in providing incentives for businesses that adhere to the mitigation strategy;
- the tolerable risk level in the Cat bonds market, both in terms of the offer by the issuer and the acceptance by investors;
- the effectiveness of risk mitigation strategies, which is a challenging factor to estimate, as it relies on the expertise of physical risk assessment without the possibility to draw data from previous observations

Conclusions and perspectives

In particular, our approach provides insights on how the synergy between the insurance market and the public system could lead to achieving full participation in projects aimed at addressing climate change risks.
The rationale behind our model is clear: insurers are no longer able to cover and compensate for extreme losses from natural events caused by climate change. However, what they can do is to protect and promote the green transition in cooperation with public administration.

Main references

[1] Botzen W.J.W., Van Den Bergh J.C.J.M., (2008) Insurance Against Climate Change and Flooding in the Netherlands: Present, Future, and Comparison with Other Countries. Risk Analysis, 28(2):413–426.

2] Fabio Castelli, Marcello Galeotti, and Giovanni Rabitti (2019). Financial Instruments for Mitigation of Flood Risks: The Case of Florence. Risk Analysis, 39(2):462–472.

3] Riccardo Cesari, Leandro D'Aurizio. Calamità naturali e coperture assicurative: valutazione dei rischi e policy options per il caso italiano. 2020.
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4] Marcello Galeotti, Marc Gurtler, and Christine Winkelvos. Accuracy of Pre mium Calculation Models for CAT Bonds - An Empirical Analysis. Journal of Risk and Insurance, 80(2):401–421, 2013.

5] EIOPA (2023). The role of insurers in tackling climate change: challenges and opportunities.

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